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CHALLENGES AND OPPORTUNITIES OF FLUID SIMULATION GRAPH BASED APPROACHS

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Abstract- Fluid simulation is one of the old topics but still have wide opportunities to be researched, as fluid simulations have applications in various fields especially for experimentation, multimedia, movie, games and virtual reality. Fluid simulation become more popular when incompressible Navier-Stokes equations proposed. Many fluid simulation approaches based on incompressible Navier-Stokes equations emerge till today. This paper presents the results of a survey of several scientific articles that discuss the synthesis approach for fluid simulation, especially graph based fluid simulation. Generally, fluid simulation approach consists of physical based and synthesis based. Physical based has limitations in terms of computational cost and complexity. Researchers have proposed at least three approaches to overcome this, ie modifications to a physical-based approach, parallelization of a physical based approach, and a synthesis based approach. The synthesis approach has many approaches, including machine learning, deep learning, convolutional network, graph, etc. An interesting point for this synthesis approach is that computational cost and complection are significantly reduced compared to physical based, but the visualization of the resulting fluid is evident. Although this synthesis approach still has weaknesses in terms of accuracy, this method is interesting to be developed further for game and virtual reality purposes. This paper presents the challenges and opportunities of fluid simulation graph based on paper's survey result.
Keywords – fluid simulation, approach, graph based, synthesis

1. INTRODUCTION

Visualizing real objects naturally is one of the most interesting areas of study on computer graphics. It is very useful to describe various natural phenomena such as fluid moving, otomotive design, cloth simulation, and others that support academic and industrial research

Fluid dynamics is one of the disciplines that examines the behavior of liquids and gases in a state of silence or movement and their interaction with other objects. The phenomenon of fluid dynamics has been studied since the 16th century by Da Vinci by observing the flow. Then Newton expressed the concept of Newtonian viscosity in the 17th century, and followed by discoveries by many other great scientists. Important contributions were given by Navier in 1823 and Stokes in 1845 separately. They derive partial differential equations of viscous fluid, which discuss about viscous fluid motion equations, known as the Navier-Stokes equation. The Navier-Stokes equation is the basis for the study of fluid dynamics until now.

To simulate the movement of substances that are continuum, such as fluid or deformable solid, common approaches used are Lagrangian and Eulerian. The researchers developed both of these approachs to simulate or make the fluid animation look real with low cost. Stam (1999) proposed a stable model using the Eulerian approach, and after that many researchers elaborate Stam's idea. Gingold, etc (1977) introduce Smoothed Particle Hydrodynamics (SPH) methode which implemented in astrophysics. This method is a mesh free Lagrangian, where the coordinates can change following fluid movement. Monaghan (1995) for the first time implemented SPH for fluid simulation, and afterwards many other researchers used SPH with various improvisations for fluid simulation.

The Lagrangian and Eulerian approach is also known as the physical-based approach. Generally, the physical-based approach produces simulations with visible visualizations and high accuracy, but has weaknesses in terms of computational cost and high complexity. There are three ways that the researchers have proposed to overcome these weaknesses. The first way is to modify the physical-based approach, as proposed by Foster (2001), Lassaso, etc (2008), and Cohen, etc (2010). The second way is to parallelize the physical-based methods by utilizing the Graphics Processing Unit (GPU), as proposed by Qing Dai and Xubo Yang (2013) and Rustico, etc (2014). The third way is to use the synthesis method. Zhang, etc (2011) proposed fire synthesis simulation graph based. Sato, etc (2016) proposed synthesis fluid simulation flow-field based. Grover, etc (2016) proposed sinthesis fluid simulation motion graph based. Yang, etc (2016) proposed sinthesis fluid simulation Artficial Neural Network (ANN) based. The synthesis approach has a positive effect on reducing computational cost, but it has weaknesses in terms of accuracy.

Many synthesis approaches are utilized for current fluid simulations, such as games, virtual reality, and other visualizatons. In general, this synthesis approach fits with applications that require visualization that looks real and realtime, rather than experimental ones. Explore this synthesis method becomes an interesting thing considering the current and future needs in terms of visualization and virtual reality.

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This paper present the results of a survey of several scientific articles that discuss the approaches of fluid simulation, especially graph based fluid simulation. Then we elaborate the opportunities and challenge the fluid simulation graph based.

2. SURVEY OF FLUID SIMULATION APPROACHES

Fluid is a deformable substance that flows and has no fixed shape. Fluid is divided into two categories: compressible and incompressible. The compressible fluid is a fluid whose density may change due to changes in pressure and temperature such as nitrogen and oxygen gas. While the incompressible fluid is a fluid whose density is constant against pressure changes such as water.

Navier-Stokes is the most commonly used mathematical model for fluid movement. In this fluid simulation model there are several variables that need considering such as velocity of the fluid movement, the density of the fluid, the pressure produced by the fluid, and the forces affecting the fluid. This below the Navier Stokes equation.

$$\frac{d\vec{u}}{dt} + \vec{u}.\nabla\vec{u} + \frac{1}{\rho}\nabla p = \vec{g} + v\nabla.\nabla\vec{u} \quad (1)$$

$$\nabla\vec{u} = 0 \quad (2)$$

Fluid velocity $\vec{u}$, refer to three components of velocity (u, v, w), where u represent x, v represent y, dan w represent z. ρ represent density of fluid, p represent pressure, and v represent the viscocity of fluid. Equation (1) know as momentum equation and equation (2) illustrate the incompreesible condition.

2.1 Survey of fluid Simulation approach

When discussing the continuum moving (fluid or deformable solid), there are two common approaches or perspectives used, they are Eulerian and Lagrangian. Lagrangian approach (particle based), treating fluids like particle systems. Each particle point on a fluid or solid has properties position(x) and velocity (v). Discrete particles are connected in a mesh. Eulerian approach (grid based) consider the particles as something fixed and observe the quantity attributes of fluid such as velocity, temperature, and density. They are measured measured at those points that change over time. Then semi-Lagrangian, a perspective that is also widely used, using the Euler framework but the discrete equations come from the Lagrangian perspective.

The Navier-Stokes equation is the basis for the study of fluid dynamics until now. Initially the fluid simulation was performed by physical-based method with the general approach or point of view used were Lagrangian and Eulerian. Gingold, etc (1977) introduce Smoothed Particle Hydrodynamics methode (SPH) which is implemented in astrophysics. This method is a mesh free Lagrangian, where the coordinates can change following fluid movement. Monaghan (1995) for the first time implements SPH for fluid simulation, and afterwards many other researchers used SPH with various improvisations for fluid simulation.

Stam (1999) proposed a stable model using the Eulerian point of view, and after that many development researchers who developed the idea Stam. Pada 2001, Ronald Fedkiw, Joe Stam, and Henrik Wann Jensen researched about visual simulation smoke and result the natural and stable model as picture below.

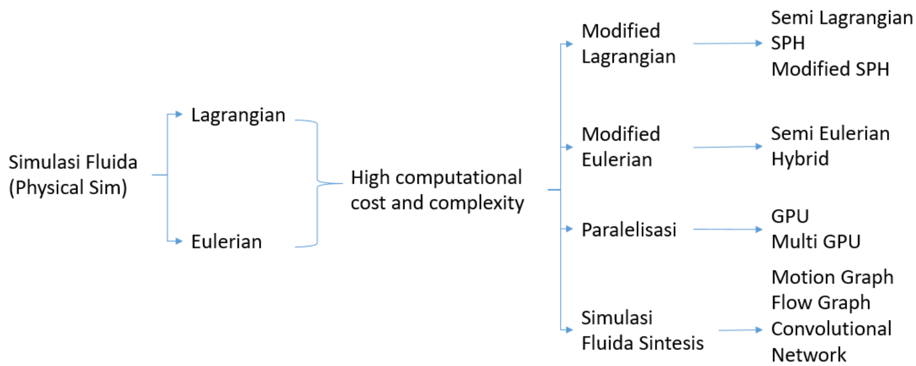
Picture 1. Smoke Simulation[5]

Jonathan M. Cohen (2010), reviewed some techniques for recomputing grid-based fluid calculations from grid-free particle simulation. Eulerian algorithm for fluid simulation with high robust level and runs effectively in GPU. Youquan Liu (2004) solve the Navier Stokes equation by using the semi Langrangian method on the GPU, so that run on a GPU with the ability to process boundary / surface changing conditions generated from gemoetric forms with parallel performance. However, this method still has limitations if implemented for large-scale cases. A high-performance computing approach is needed to reduce time complexity and algorithms[28].

Physical-based methods give simulations with high accuracy, but has weaknesses in terms of computational cost and high complexity. There are three ways that the researchers proposed to overcome these weaknesses, they are modifications to the Lagrangian and Eulerian approaches, parallelization techniques, and synthesis approaches.

Grid Based Numerical method has an important role in fluid simulation, although it still has limitations. Suppose a complex fluid simulation (with many grids) will take a long computational time and large memory. Fengquan Zhang (2011) propose some alternatives of solution to solve the problem by using SPH approach so result better performance. Solenthaler (2009) propose the predictive-corrective incompressible SPH (PCISPH) methode and produce better performace than common methode weakly compressible SPH (WCSPH).

Based on the survey of more than 50 scientific articles, it is seen that the research on fluid simulation has been very wide with various approaches. Software and applications are also very much produced. The fluid simulation research also has a very wide coverage. From the type of fluid such as smoke, water, or fire. Then each type of fluid has various characteristics. Suppose a fluid simulation for water, water can be viewed from water in containers, water on the beach, running water, surface water, water waves on the beach, deep sea water waves, water splashes, and others. Different types and fluid characteristics will of course affect the model and approach to be used. The picture below describe varoius of fluid simulation approachs based on survey paper.



Picture 2. Fluid Simulation Approachs

Physical-based methode produce the simulation with high accuration but has high computational cost and complexity. At least, there are three categories of methodes to evercome the limitation. They are modified physical based, paralelization, and synthesis methode. The first methode proposed by Foster (2001), Lassaso, etc (2008), and Cohen etc (2010). The second methode proposed by Qing Dai and Xubo Yang (2013) and Rustico etc (2014). And the last methode proposed by Zhank etc (2011), Sato etc (2016), Grover etc (2016), and Yang etc (2016).

2.2 Graph based fluid simulation, challenge and opportunity

Many researchers have propose various synthesis methode to produce fluid simulation with less computational cost and complexity. Some of them based on graph. For example, Zhang etc (2011) proposed fire synthesis simulation flow graph based, Sato etc (2016) proposed fluid simulation flow-field based, Grover etc (2016) proposed fluid simulation motion graph based.

Fluid simulation graph based become interesting to be researched. It has less computational cost and complexity, but produce simulation and animation with good visualization. Even though some researchers doubt the accuracy. So, graph based approach have chances to implemented in some areas which need quality of visualizatition more than accuracy such as games, movie, and virtuality. On the other hand the challenge is how to increase the accuracy while keep the computational cost and complexity low. The combination of graph based approach and physical based approach possible to solve this challenge.

3.CONCLUSION

Physical-based methods produce simulations with high accuracy, but have weakness in computational cost and high complexity. There are three approaches the researchers proposed to overcome the weaknesses, namely modifications to the Langrangian and Eulerian approaches, parallelization techniques, and synthesis approaches.

Fluid simulation graph based produces fluid simulation with low computational cost, low complexity, and good visualization quality. The weakness is some researchers doubt accuracy. Thus condition bring the opportunity to impelement fluid simulation graph based in movie and virtuality area. And the challenge is how to increase the accuracy.

4. REFERENCES

[1] Bridson, R.. Fluid Simulation for Computer Graphics. Wellesley, Massachusetts: A K Peters, Ltd, 2008.

[2] Becker, Markus and Tescchner , Matthias (2007). Weakly compressible SPH for free surface flows. ACM SIGGRAPH Symposium on Computer Animation (2007)

[3] Bridson, R. (2008). Fluid Simulation for Computer Graphics. Wellesley, Massachusetts: A K Peters, Ltd.

[4] Chladek, Michal dkk (2015). Shallow Water Simulation based on SPH with Irregular Simulation Domains. SCCG '15 Proceedings of the 31st Spring Conference on Computer Graphics pages 63-63

[5] Cohen, Jonathan (2010). Interactive Fluid-Particle Simulation using Translating Eulerian Grids. Proceedings of the 2010 ACM SIGGRAPH symposium on Interactive 3D Graphics and Games

[6] Dai, Qing and Yang, Xubo (2013). Interactive Smoke Simulation and Rendering on the GPU. VRCAI 2013

[7] Feng, Yufen (2011), Simulation of Real Water in 3D Animation. 2011 International Conference on Multimedia Technology (ICMT)

[8] Fedkiw, R., Stam, J., & Jensen, H. W. (2001). Visual Simulation of Smoke. Stanford University.

[9] Feng, Yufen and Zhan, sheng (2009). Simulation of Real Water in 3D Animation

[10] Fitriyani, Izzatul Ummah, "A Research On Parallel Computing Using Ant Colony Optimization Algorithm To Distribute Jobs Among Processors In The System Environment", ICTS 2013

[11] Foster, N., Fedkiw, R. (2001) Practical animation of liquids. Proceedings of SIGGRAPH, pp. 23–30

[12] Gao, Xiaopeng, dkk. (2010). Accelerate Smoothed Particle Hydrodynamics Using GPU. Information Computing and Telecommunications (YC-ICT), 2010 IEEE Youth Conference

[13] Goswami, Prashant (2010). Interactive SPH Simulation and Rendering on the GPU. Eurographics/ ACM SIGGRAPH Symposium on Computer Animation (2010)

[14] J.J.Monaghan, A.Kocharyan (1995) SPH Simulation of Multi-phase Flow. Computer Physics Communications, pp. 225-235.

[15] L. B. Lucy. "A numerical approach to the testing of the fission hypothesis", The Astronomical Journal, pp.1013–1024, 1977.

[16] Lagergren, Mattieas dkk (2010). High-detailed fluid simulation on the GPU SIGGRAPH 2010

[17] Lenaerts, Toon and Dutre, Philip (2009). Mixing Fluids and Granular Materials. Eurographics 2009 Volume 28 Number 2.

[18] Liu, Sighuang and Liu, Qiguang, and Peng, Qunsheng (2011). Realistic Simulation of Mixing Fluids. The Visual Computer (Springer) March 2011, Volume 27, Issue 3, pp 241–248

[19] Liu, Youquan (2004). Real-Time 3D Fluid Simulation on GPU with Complex Obstacles. Proceedings of the 12th Pacific Conference on Computer Graphics and Applications

[20] Lossasso, Frank (2008). Two-Way Coupled SPH and Particle Level Set Fluid Simulation. IEEE Transactions on Visualization and Computer Graphics (Volume: 14, Issue: 4, July-Aug. 2008)

[21] Lambright, B. (2013). Eulerian Smoke Simulation. Bournemouth, UK: Bournemouth University – NCCA

[22] Keever, erik and Imamura, James. Imogen: A Parallel 3D Fluid and MHD Code for GPUs. ICS'13 June 10–14, 2013, Eugene, Oregon, USA., ACM 978-1-4503-2130-3/13/06.

[23] Playne, D.P. dkk (2014) Simulating and Benchmarking the Shallow-Water Fluid Dynamical Equations on Multiple Graphical Processing Units. CRPIT Volume 152 - Parallel and Distributed Computing 2014

[24] Rustico, Eugenio, dkk. (2014). Advances in Multi-GPU Smoothed Particle Hydrodynamics Simulations. IEEE TRANSACTIONS ON PARALLEL AND DISTRIBUTED SYSTEMS, VOL. 25, NO. 1, JANUARY 2014

[25] Solenthaler and Pajarola (2009). Predictive-Corrective Incompressible SPH. ACM Transactions on Graphics (TOG) - Proceedings of ACM SIGGRAPH 2009

[26] Stam, J. (1999). Stable fluids. Proceedings of ACM SIGGRAPH, pp. 121–128

[27] Stam, J. (2003). Real-Time Fluid Dynamics for Games. Proceedings of the Game Developer Conference

[28] Sibaroni, Yuliant. Fitriyani., and Nhita, Fhira. (2016) The Optimal High Performance Computing Infrastructure for Solving High Complexity Problem Journal of Telkomnika. Vol.14, No.4, December 2016 p 281

[29] Wang, Yingrui and Li, Leisheng (2016). GPU Acceleration of Smoothed Particle Hydrodynamics for the Navier-Stokes Equations. : 2016 24th Euromicro International Conference on Paarllel, Distributed, and Networks-Based Processing

[30] Zhang, Fengquan (2011). A SPH Methode For Interactive Fluids Simulation on The Multi-GPU. VRCAI 2011, Hongkong

[31] Zhang, Fengquan (2011). SPH-based Fluid Simulation: A Survey. 2011 International Conference on Virtual Reality and Visualization

[32] Zhang, Fengquan, dkk (2011) A SPH-Based Method For Interactive Fluids Simulation On The Multi-GPU. VRCAI '11 Proceedings of the 10th International Conference on Virtual Reality Continuum and Its Applications in Industry

[33] NVIDIA. "Parallel Programming and Computing Platform | CUDA | NVIDIA | NVIDIA". http://www.nvidia.com/object/CUDA_home_new.html.

[34] Stam, J. (2003). Real-Time Fluid Dynamics for Games. Alias | wavefront.

[35] Sunpyo Hong, Hyesoon Kim, "Memory-level and Thread-level Parallelism Aware GPU Architecture Performance Analytical Model", ISCA'09 Proceeding, ACM, 2009

[36] Thomas Rauber, Gudula Runger, "Parallel Programming For Multicore and Cluster Systems", Springer, 2010.

[37] http://www.cs.tufts.edu/comp/140/lectures/Day_15/CUDA_Memory_Model.pdf , dikases pada 20 Mei 2016